Races of *Puccinia graminis* in the United States and Mexico During 1983

A. P. ROELFS, Research Plant Pathologist, D. H. CASPER, Research Technician, and D. L. LONG, Plant Pathologist, Cereal Rust Laboratory, ARS, USDA, University of Minnesota, St. Paul 55108

ABSTRACT

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Oat stem rust was present in trace amounts in the southern United States in 1983. Disease development was generally a week later than the 40-yr average. Losses were light throughout the United States. No isolates were obtained from Mexico. The principal race was NA-27, virulent on host genes *Pg*-1, -2, -3, -4, and -8, making up 88% of the isolates. No virulence was found in oat stem rust for host genes *Pg*-13, 16, or -a. Wheat stem rust was found in trace amounts in southern Texas in mid-March. Stem rust spread northward into the northern Great Plains by mid-June. Although moderate severities occurred in some hard red spring wheat fields, the cultivars had adequate resistance to prevent the massive inoculum levels of the mid-1950s and losses were minimal. Race 15-TNM, virulent on *Sr*17, was the most common virulence combination, making up 70% of the 1,295 isolates from 466 collections. The second most common race was *Sr*17 avirulent on 15 TNM, which made up 24% of the isolates. No virulence was found on wheat lines with genes *Sr*13, 22, 24, 25, 26, 27, 29, 31, 32, 33, 37, Gt, and Wld-1.

Puccinia graminis Pers. has been a major pathogen of many small-grain cereals worldwide. Since the virtual elimination of susceptible barberry bushes from the north central United States, the frequency of epidemics in this area has been reduced (4). Nevertheless, devastating epidemics occurred on wheat in 1935, 1937, 1953, and 1954 and on oats in 1953 in the United States (3) from windborne uredospores. To avoid such epidemics, resistant cultivars were developed that may in turn become susceptible to new pathogen races. Thus, constant monitoring of changes in pathogen virulence has been part of the program to have epidemic-free crops. Data from these surveys also contain information on the effects of changes in host resistance on pathogen frequency and distribution.

MATERIALS AND METHODS

Field surveys were made over a 24,000-km route covering the Great Plains and the Gulf Coast of the United States. The surveys followed a preselected, generally circular route through areas where small-grain cereals are important and rust has historically been a problem. Stops were made at a commercial field each 32 km or at the first field thereafter. Additional stops were made at experimental nurseries and wheat trap plots along the route. Whenever rust was observed in a field or nursery, a varying number of leaves or stems bearing rust uredia from a single plant or cultivar were collected. These collections were supplemented by others furnished by cooperators throughout North America.

In 1983, field surveys were conducted in the following areas: southern Texas and northeastern Mexico (late March), northern Texas and the Gulf Coast (late April), Oklahoma and Kansas (mid-May), Nebraska and South Dakota (mid-June), the eastern Dakotas and Minnesota (early July), and the north central United States and Manitoba (late July and early August). When uredial collections were brought to the laboratory, two spore samples were collected. One portion was used to inoculate 7-day-old seedlings of a susceptible host (when the forma specialis was known) or a group of potentially susceptible hosts treated with maleic hydrazide to enhance spore production. Each culture was maintained in a separate clear-plastic chamber. After 12–14 days, up to four leaves bearing or pruned to bear a single uredium were saved and reincubated to permit loose uredospores to germinate. Uredospores were collected separately 3–4 days later from up to three uredia (each such collection an isolate); each uredium provided enough spores to inoculate a differential host series.

Spores suspended in a lightweight mineral oil were sprayed on plants, which were then placed in a dew chamber

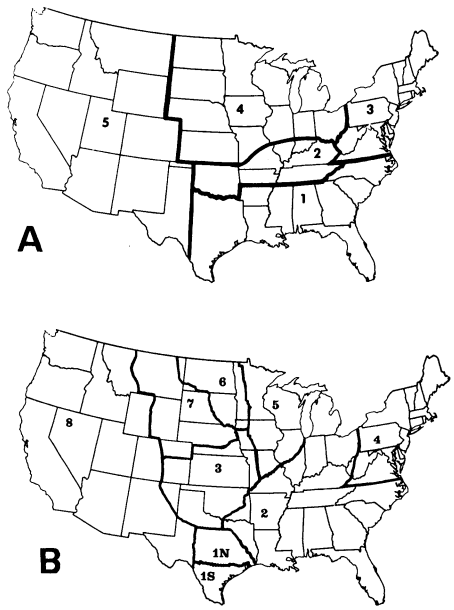

Fig. 1. Ecological areas for *Puccinia graminis* in the United States. **(A)** Areas for oat stem rust: (1) winter oats, (2) mixed winter and spring oats, (3) spring oats and barberry area, (4) major spring oat-producing area, and (5) widely isolated oat fields. **(B)** Areas for wheat stem rust: (1S) mainly fall-sown spring wheat, (1N) mixed wheat types, (2) soft red winter wheat, (3) southern hard red winter wheats, (4) mostly soft red winter wheat and barberries, (5) mixed wheat types and widely dispersed fields, (6) hard red spring and durum wheats, (7) northern hard red winter wheat, and (8) various winter and spring wheats.

Table 1. A key defining the Cereal Rust Laboratory races of *Puccinia graminis* f. sp. *tritici*

Code[a]	Response of host with *Sr* genes[b]			
Set 1:	5	9d	9e	7b
Set 2:	11	6	8	9a
Set 3:	36	9b	13	10
B	R	R	R	R
C	R	R	R	S
D	R	R	S	R
F	R	R	S	S
G	R	S	R	R
H	R	S	R	S
J	R	S	S	R
K	R	S	S	S
L	S	R	R	R
M	S	R	R	S
N	S	R	S	R
P	S	R	S	S
Q	S	S	R	R
R	S	S	R	S
S	S	S	S	R
T	S	S	S	S

[a] Combination of host responses from set 1 determines the first letter of code, set 2 the second, and set 3 the third.
[b] R = host not susceptible; S = host susceptible.

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overnight at 18 C. This was followed by a 3-hr period of fluorescent light (10,000 lux) as the temperature rose gradually to 30 C. Plants were then placed in a greenhouse at 18–28 C. Infection types were observed after 10–14 days.

The second sample of spores from each collection was bulked with those from other collections made in the same area at about the same time and was used to inoculate a "universally" resistant series.

P. graminis* f. sp. *avenae. The differential host series consisted of oat lines with genes *Pg*-1, -2, -3, -4, -8, -9, -13, -15, -16, and -a (2). The universally resistant series consisted of the host lines Saia (CI 7010), CI 7221, S.E.S. Selection 52 (CI 3034), X-1588-2 (CI 8457), Kyto (CI 8250), MN 730358, and CI 9139. These lines had been selected over a period of years as resistant to stem rust. Data from the United States were grouped corresponding to five ecological areas (Fig. 1A) on the basis of oat production, cultural practices, and geographic separation.

P. graminis* f. sp. *tritici. The differential host series consisted of wheat lines with genes for *Sr*5, 6, 7b, 8, 9a, 9b, 9d, 9e, 10, 11, 13, 15, 16, 17, 36, and Tmp. Races were assigned using the code shown in Table 1. The universally resistant series consisted of lines with the host genes *Sr*22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 37, Gt, and Wld-1 and the cultivars Era, Cando, Olaf, Leeds, and Ward. These lines and cultivars had been selected over a period of years as resistant to stem rust.

Data were grouped into nine ecological areas (Fig. 1B). Area 1S has mainly fall-sown spring wheats; area 1N, mixed wheat types; area 2, mostly soft red winter wheat; area 3, southern hard red winter wheat; area 4, mostly soft red winter wheat and scattered barberries; area 5, mixed wheat types; area 6, hard red spring and durum wheat; area 7, northern hard red winter wheat; and area 8, mostly soft winter and spring wheats.

RESULTS AND DISCUSSION

Data from collections made from commercial fields and naturally occurring hosts were separated from those made in nurseries and plots. No data were included from collections made in or near known inoculated nurseries.

P. graminis* f. sp. *avenae. Rust was first observed in a farmer's field in Hidalgo County, TX, on 20 March. No oat stem rust was found at Beeville, TX, until mid-April, nearly 3 wk later than the 40-yr mean (6). By mid-May, traces of stem rust were found in scattered locations throughout the Southeast from central Texas to northwestern Florida. These areas provided inoculum for the northern oat-growing region, where rust occurred in light amounts. The initial infections were sporulating by early July, a week later than normal. This outbreak was terminated by crop maturity before there was significant loss.

The principal race in the United States was race NA-27, making up 88% of the isolates (Table 2). This race has predominated in the U.S. population since 1965. NA-27 is virulent on host genes *Pg*-1, -2, -3, -4, and -8, but only *Pg*-2 and -4 are widely used in commercial cultivars. NA-27, however, has caused only one moderately severe epidemic (6). Race NA-16, which has tended to be more common in the population obtained from wild oats and susceptible cultivars, was again the second most frequent, and in 1983, it made up 7% of the U.S. population. Race NA-5 is avirulent on some of the earliest studied resistance genes, *Pg*-1, -2, -4, and -8, but virulent on *Pg*-15. It was an important component of the pathogen population in Texas and Idaho and was found in an Illinois nursery. Races NA-1 and NA-24 were found in trace amounts on wild oats in North Dakota and in a nursery in New York, respectively. Virulence for the single genes used for race identification is shown in Table 3. Host genes *Pg*-13, -16, and -a were resistant to the population we sampled from the United States in 1983; however, virulence for these genes has been found in the past. No isolates were obtained from the single collection of stem rust made in Mexico. Seven of the nursery collections from Canada were from Ontario and would appear to be in part from a sexually reproducing population because of the diversity in virulence combinations detected. The field collections were from Manitoba, where race NA-27 predominated as it did in the north central United States.

P. graminis* f. sp. *tritici. Stem rust was found in mid-March in wheat trap plots at Victoria and Beeville, TX, and in late

Table 2. Frequency of the identified races of *Puccinia graminis* f. sp. *avenae* by area and source of collection in 1983

Area[a]	Source	Number of[b]		Percentage of each North American (NA) physiologic race[c]					
		Collections	Isolates	1	5	6	16	24	27
United States	Field	129	261	1	···	1	4	···	93
	Nursery	289	739	···	6	···	7	···	86
	Total	418	999	*[d]	4	*	7	···	88
1	Field	4	12	···	···	···	8	···	92
	Nursery	198	510	···	4	···	10	···	86
	Total	202	522	···	4	···	9	···	86
2	Nursery	1	3	···	···	···	···	···	100
3	Field	1	···	···	···	···	···	···	···
	Nursery	2	4	···	···	···	···	50	50
	Total	3	4	···	···	···	···	50	50
4	Field	124	249	1	···	1[e]	4	···	93
	Nursery	81	205	···	2	···	3	···	95
	Total	205	454	1	1	···	4	···	94
5	Nursery	6	16	···	100	···	···	···	···
6	Nursery	1	0	···	···	···	···	···	···
Mexico	Nursery	1	0	···	···	···	···	···	···
Canada[f]	Field	22	57	···	2	···	···	···	89
	Nursery	9	25	···	···	···	···	···	56

[a] See Figure 1A for ecological areas in the United States.
[b] Uredia from a single field, plant, or cultivar received separately was a collection from which up to three single pustule isolates were identified.
[c] From Martens et al (2).
[d] Less than 0.6% of the isolates.
[e] Isolated from aeciospores.
[f] The three collections (nine isolates) from Ontario fields were NA-27 (four isolates) and NA-25 (five isolates), 9%. Seven collections (19 isolates) from the Ontario nursery included isolates of NA-11, 12%; NA-12, 4%; NA-25, 24%, and NA-26, 4%.

Table 3. Incidence of virulence in *Puccinia graminis* f. sp. *avenae* isolates to the resistance of the single-gene differential lines in the 1983 survey

Area[a]	Percentage of isolates virulent on *Pg* gene[b]						
	-1	-2	-3	-4	-8	-9	-15
1	96	86	100	100	96	0	4
2	100	100	100	100	100	0	0
3	100	100	100	100	50	0	0
4	98	94	98	94	95	1	2
5	0	0	100	0	0	0	100
United States 1983	95	88	100	88	95	*[c]	5
United States 1982[d]	95	89	100	88	89	0	5
United States 1981[d]	99	96	100	96	99	*	1

[a] See Figure 1A for ecological areas in the United States.
[b] No cultures were virulent on *Pg*-13 or -16.
[c] Less than 0.6% of the isolates.
[d] Roelfs et al (9,10).

April and early May in the southern parts of Georgia and Louisiana, respectively. By mid-May, traces of stem rust were found in northern Texas (area 1N), central Oklahoma, and northeastern Kansas. By 16 June, stem rust was present in trace amounts at Brookings and Highmore, SD, and on 6 July, throughout the northern Great Plains. Disease development was restricted because nearly all of the acreage was planted to resistant cultivars; however, because of the early arrival of inoculum (2 wk before the long-term average [1] at Brookings), a significant buildup of inoculum occurred. Many fields were observed with 5–20% severities of moderately resistant infections (infection types 1 and 2). Little damage resulted with this level of disease. A total of 466 collections were obtained in 1983 (Table 4), the most since 1976 (7). In 1983, 131 collections were received from commercial fields of wheat, barley, and uncultivated hosts, whereas only 11 such collections were made in 1982 and only one of those was from a wheat field. This severity of stem rust in 1983 was such, however, that enough inoculum was generated to result in large numbers of infections, and if resistant cultivars had not limited both uredial numbers and spore production, the disease loss in the northern Great Plains would have been severe.

The most common race in the United States again was 15-TNM, making up 65% of all isolates (Table 4); however, 77% of the isolates of this race are virulent on hosts with *Sr*17. Races 151-QFB and -QCB were present in small amounts throughout most of the United States. These races are similar, differing only in virulence on *Sr*8 (151-QFB). Races 113-RKQ and -RTQ also were found in small amounts. They differ in that 113-RKQ is avirulent on *Sr*11. Two forms of race RKQ existed and both were present in trace amounts. Race 56-MBC still exists in trace amounts (one collection from an Iowa nursery and one collection from a commercial winter wheat field in Wisconsin). These two cultures of MBC differ in their ability to attack Triumph 64 (*Sr* Tmp) (Table 3). For the first time in many years, race 151-QSH, first found in the late 1960s, was not detected. It is not known whether this indicates that the virulence combination was eliminated from the population or has decreased below the threshhold of detection. Race 15-TBM, which had not been found since 1979, was found again in 1983. It differs from TNM in avirulence on *Sr*8 and 11. The collections from Mexico were all made in the fall of 1983, mainly from nurseries in the highlands from Mexico City and to the northwest. No stem rust was found in northeastern Mexico in March 1983.

The collections from area 8 (Tables 4 and 5) were nearly all from the Pacific Northwest. The differences from the Great Plains (areas 1N, 3, 6, and 7) in virulence combinations (Table 4) and frequency of virulence (Table 5) are due to frequent sexual recombination in that population.

Two new virulence combinations were found in Mexico. Race 14-GFC is phenotypically nearest to race 151-QFB but is virulent on *Sr*10 and avirulent on *Sr*5, 12, 14, 16, dp-2, and Kt '2.' Such a great difference indicates little chance of an asexual relationship between the

Table 4. Summary of the identified races of *Puccinia graminis* f. sp. *tritici* by area and source of collection in 1983

				Percentage of isolates of each race[c]												
		Number of[b]		11	15			17	56		113			151		
Area[a]	Source	Collections	Isolations	RCR	TBM	TNM	TNM[d]	HNL	MBC	MBC[e]	RKQ	RKQ[d]	RTQ	QCB	QFB	Others[f]
United States	Field	131	356	...	...	19	78	...	...	*	...	1	...	1	*	...
	Nursery	335	939	1	*[g]	26	61	...	...	*	*	*	1	4	1	...
	Total	466	1,295	1	*	24	70	...	...	*	*	*	1	3	1	...
1S	Nursery	37	91	...	...	15	50	...	...	...	...	...	5	25	3	...
1N	Field	1	1	...	...	...	...	...	...	...	...	...	...	...	100	...
	Nursery	10	30	...	...	...	57	3	...	...	...	...	3	37	...	...
	Total	11	31	...	...	...	55	3	...	...	...	...	3	35	3	...
2	Field	1	3	...	...	...	100	...	...	...	...	...	...	...	...	...
	Nursery	34	98	12	...	26	58	...	...	...	1	...	2	...	1	...
	Total	35	101	12	...	25	59	...	...	...	1	...	2	...	1	...
3	Field	22	66	...	...	12	87	...	...	...	...	...	...	...	2	...
	Nursery	30	82	...	...	10	90	...	...	...	...	...	...	...	...	...
	Total	52	142	...	...	11	89	...	...	...	...	...	...	...	1	...
4	Field	1	3	...	...	...	...	...	100	...	...	...	...	...	...	...
	Nursery	1	3	...	...	...	33	...	...	...	...	...	...	...	67	...
	Total	2	6	...	...	...	17	...	50	...	...	...	...	...	33	...
5	Field	12	33	...	...	21	73	...	...	6	...	...	...	...	...	...
	Nursery	38	112	...	...	40	57	...	...	1	...	1	...	...	...	...
	Total	50	145	...	...	35	61	...	...	2	...	1	...	...	...	...
6	Field	92	244	...	...	21	76	...	...	...	...	1	...	1	...	...
	Nursery	181	515	...	*	29	70	...	...	...	...	...	...	...	...	...
	Total	273	759	...	*	27	71	...	...	...	...	*	...	*	...	...
7	Field	2	6	...	...	17	83	...	...	...	...	...	...	...	...	...
	Nursery	3	5	...	...	...	100	...	...	...	...	...	...	...	...	...
	Total	5	11	...	...	9	91	...	...	...	...	...	...	...	...	...
8[h]	Nursery	32	89	...	...	...	3	...	...	...	...	...	...	...	...	97
Mexico[i]	Nursery	69	113	1	...	3	3	...	5	3	2	1	24	8	36	12
Canada[j]	Field	21	56	...	...	11	86	...	...	...	...	...	...	...	2	2
	Nursery	14	38	...	...	5	58	...	...	8	5	...	...	...	5	19

[a] See Figure 1B for ecological areas in the United States.
[b] Uredia from a single field, plant, or cultivar received separately was a collection from which up to three single-pustule isolates were identified.
[c] Cereal Rust Laboratory races (Table 1).
[d] Also virulent on *Sr*17.
[e] Also virulent on *Sr*Tmp.
[f] Does not include 31 collections and 86 isolates from Washington (area 8) that were from a sexually reproducing population.
[g] * = Less than 0.6% of the isolates.
[h] The collection from California was race 15-TNM; the other races from Washington were 23-BBC from field, nursery, and total, 88, 83, and 85%, respectively, with lesser amounts of LCC, QCC, AND QDC.
[i] The other races from Mexico were race 14-GFB, 16%; and 56-MBC, avirulent on *Sr*15 and Tmp, 1%.
[j] The other races identified from nurseries were RCC, from aecia from Ontario, 3%; 23-BBC from Alberta, 8%; 15-TLM, Ontario and from field collections, 8%; and 15-TDM from Manitoba, 2%.

Table 5. Incidence of virulence in *Puccinia graminis* f. sp. *tritici* isolates to the resistance of single-gene differential lines used in the 1983 survey

Area[a]	Percentage of isolates virulent on *Sr* gene[b]														
	5	6	7b	8	9a	9b	9d	9e	10	11	15	16	17	36	Tmp
1S	100	5	71	75	36	5	100	66	66	71	34	100	79	71	66
1N	97	3	61	64	42	3	100	55	55	61	45	100	94	61	55
2	100	3	99	88	16	15	100	84	96	86	16	100	72	99	84
3	100	0	99	100	1	0	100	99	99	99	1	100	89	99	99
4	100	0	67	50	33	0	50	17	67	17	83	100	100	17	17
5	100	1	97	98	2	1	98	96	98	96	4	100	65	96	98
6	100	*	100	99	1	*	100	99	99	99	1	100	73	100	99
7	100	0	100	100	0	0	100	100	100	100	0	100	91	100	100
8	15	0	3	6	9	0	8	3	98	3	97	94	100	3	3
United States 1983	94	1	90	90	6	2	94	88	95	88	12	100	77	90	77
United States 1982[c]	96	9	86	92	12	8	96	78	87	82	22	99	75	84	79
United States 1981[c]	87	4	56	90	46	9	96	37	48	42	63	100	72	54	37
Mexico	88	28	42	81	85	29	90	5	6	9	93	8	0	34	8
Canada	97	2	94	84	6	2	94	87	95	86	13	100	86	89	90

[a] See Figure 1B for ecological areas in the United States.
[b] All isolates were avirulent on *Sr*13.
[c] Roelfs et al (8,10).

cultures. A form of race 56-MBC was isolated once that is identical to the previously existing 56-MBC avirulent on *Sr*Tmp, except for the additional avirulence on *Sr*15. Race 56-MBC in Mexico is often associated with triticale.

Twenty-eight collections were made in Manitoba, just north of area 6 in the United States. The 77 isolates were races 15-TNM, virulent on *Sr*17, 87%; 15-TNM, avirulent on *SR*17, 10%; 15-TDM, 1%; and 151-QFB, 1%. This pattern of races is very similar to area 6 of the United States (Table 4).

Associations of virulence or avirulence genes are common in asexual populations of *P. graminis* (5). For example, in this survey, virulence to *Sr*9e was always associated with virulence to *Sr*16, 36, and Tmp and with avirulence to *Sr*6, 9a, 9b, and 15. The association can be complete as with avirulence to *Sr*15 always being associated with virulence to *Sr*9e and vice versa, or directional, as with *Sr*9a avirulence usually but not always being associated with *Sr*9e virulence. These associations are important to know and understand when studying virulence or avirulence frequencies (Table 5). Virulence for *Sr*6 remains low in the United States and Mexico even though this gene was widely used in commercial cultivars. Virulence for *Sr*17, also widely used in North American cultivars, continues to increase (10).

During the survey, no virulence was found for *Sr*13, 22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 37 Gt, and Wld-1. Virulence for *Sr*30 has occurred in the North American stem rust population in trace amounts, although it was not detected in 1983.

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